

FLEXURALLY-RESISTED UPLIFT OF THE THARSIS PROVINCE, MARS

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The tectonic style of Mars is dominated by vertical motion, perhaps more than any of the terrestrial planets. The imprint of this tectonic activity has left a surface widely faulted even though younger volcanism has masked the expression of tectonism in many places. Geological activity associated with the Tharsis and, to a lesser extent, Elysium provinces is responsible for a significant portion of this faulting [Banerdt *et al.*, 1982; Willemann and Turcotte, 1982; Sleep and Phillips, 1985; Hall *et al.*, 1986] while the origins of the remaining features are enigmatic in many cases. The origin and evolution of the Tharsis and Elysium provinces, in terms of their great elevation, volcanic activity, and tectonic style, has sparked intense debate over the last fifteen years in the planetary geosciences community. Central to these discussions are the relative roles of structural uplift and volcanic construction in the creation of immense topographic relief. For example, Phillips *et al.* [1973] and Plescia and Saunders [1980] have argued that the presence of very old and cratered terrain high on the Tharsis rise, in the vicinity of Claritas Fossae, points to structural uplift of an ancient crust. Solomon and Head [1982] have pointed out, however, that there is no reason that this terrain could not be of volcanic origin and thus part of the constructional mechanism.

Uplift of Tharsis, if it occurred, could have taken place by some combination of buoyancy forces associated with lateral mass loss and with intrusion into the crust. By the term "flexurally-resisted uplift" (or simply "flexural uplift") we mean that flexural strains that occurred in the elastic lithosphere during uplift could not be accommodated and flexural faulting resulted. Mechanical models for Tharsis that involve flexural stresses in the lithosphere resulting from uplift have been rejected by Solomon and Head [1982], Willemann and Turcotte [1982] and Banerdt *et al.* [1982] on the basis that the tectonic pattern from the resulting stress pattern is not observed. Conversely, Hall *et al.* [1986] find tectonic evidence for flexural uplift stresses in the Elysium Province and speculate that the same process must have occurred for Tharsis but that the scale was very small or the evidence has been obliterated by subsequent volcanism and faulting.

Flexural uplift would plausibly have been an early phase in the evolution of Tharsis. Tectonic evidence, if it exists, might be found in the oldest geological units in the region, namely those associated with Claritas Fossae. Flexural uplift would produce circumferential faults or graben in the vicinity of Claritas Fossae that would lie along small circles centered on Tharsis. Examination of images and derived geological maps [e.g., Masursky *et al.* [1978] of this region reveals a distribution of extensional structures that can be classed as "circumferential." These features are confined to the two oldest units in the region: "cratered plateau material" and "old fractured plains material." The first of these

units is the oldest of the two, and the graben show relatively more extension in this unit. It is clear that Claritas Fossae, which was first cited as evidence for structural uplift of Tharsis because of its age and elevation [Phillips *et al.*, 1973], also shows clear tectonic evidence for uplift. Thus we conclude that flexurally-resisted uplift could have played an important role in the early history of Tharsis.

Flexurally uplift can be incorporated into a model for the evolution of Tharsis. From earlier studies [Banerdt *et al.*, 1982; Sleep and Phillips, 1979; 1985] we have concluded that Tharsis was in an isostatic state over much of its history. The view is adopted that flexural loading of Tharsis occurred relatively late in its history. We wish to describe a model that in its present state is consistent with the present-day topography and gravity fields, but one that follows from an isostatic configuration for which we do not know specifically the boundary conditions that were operative at the time. Sleep and Phillips [1985] examined two specific models for Tharsis. In simple terms, for reasonable depths of compensation there is no two-element isostatic model that will satisfy both the gravity and topography data [Phillips and Saunders, 1975]. What we will call Model I of Sleep and Phillips [1985] circumvents this problem by adding a second load besides topography, positive relief on the crust/mantle boundary. Both loads are compensated by Pratt density variations in the upper mantle; this is the model first described by Sleep and Phillips [1979]. Model II satisfies the boundary conditions by being superisostatic. This is essentially the model of Phillips and Saunders [1975] with partial compensation at the crust/mantle boundary, except that the excess load is supported flexurally.

Model II comes closest to describing our preferred model in its present geological state, and it can be described in terms of evolution from an earlier isostatic condition. Some 20 km of excess crustal thickness beneath Tharsis in this model [Sleep and Phillips, 1985, Fig. 10] can be interpreted in terms of crustal thickening by the magmatic products of partial melting. This could in fact be a dominant mechanism for crustal uplift, as described in the model of McKenzie [1984]. An evolutionary sequence is as follows: (1) Partial melting of a mantle source region gives rise to crustal intrusion and underplating because of the nature of early melts (denser than upper crust, less dense than mantle). (2) This leads to buoyant uplift of the crust. The overlying elastic lithosphere flexurally resists the uplift and tectonically fails. (3) Further uplift is supported isostatically as is extrusive volcanism, which commences as the partial melt products evolve to a lower density and reach the surface. Continued growth of Tharsis leads to faulting associated with isostatic stresses. Early extrusive volcanism is pyroclastic, which leads to further uplift. (4) As intrusions cool, a combination of membrane stress support and a thickening lithosphere eventually lead to flexural loads and the creation of the radial fractures on the periphery of Tharsis.

Further testing of this model will include considerations of the thermal evolution of Tharsis.

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